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Dr. Haught Chief

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TO THE THEORY OF VENUS' RADIO EMISSION

by

A. D. Kuz'min

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TO THE THEORY OF VENUS' RADIO EMISSION *

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SUMMARY

This work brings forth the analytical correlations linking the brightness temperature of planet's radio emission with the physical parameters of its surface and atmosphere, taking into account that the latter is absorbing. For the particular cases of absorption by the entire thickness of the atmosphere and of absorption in a uniform and parabolic layers, numerical solutions are obtained. The latter are used to interpret the results of radioastronomical measurements of Venus.

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1.- One of the important sources of information on the physical properties of Venus are its radioastronomical investigations. To interpret the latter it is necessary to establish a link between the measured quantities with the physical parameters of Venus' surface and atmosphere which exert an influence on the character of its radio emission. Among such parameters are the temperature and the emitting capability of its surface, and also the temperature and absorption in the atmosphere.

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* K TEORII RADIOIZLUCHENIYA VENERY

Inasmuch as most of contemporary ground radiotelescopes lack the resolving strength sufficient to outline areas, smaller than Venus' disk, the measurable quantity is usually the brightness temperature, averaged along the visible disk of the planet, $\overline{T_{\text{я B}}}$. In connection with this, it is necessary to find the connection between the averaged brightness temperature and the above referred to parameters of the planet.

For a planet devoid of atmosphere, a similar problem was resolved by Troitskiy [1, 2] (see also [3]). However, as is well known, Venus is surrounded by an atmosphere that may be absorbing, and consequently, it can be emitting in the radioband. Moreover, in the general case, there may exist above the planet's surface, some absorbing-emitting layer. That is why, the emission of planet's very surface and the effect upon it of the indicated absorbing media ought to be considered *

2.- Let us find the emission of an elementary area of planet's disk, surrounded by atmosphere, in a general form.

The effective emission temperature of a surface element is

$$T_e = T_{e\,0}(1 - R). \tag{1}$$

Here R is the reflection factor of the considered element in the direction of the observer,

$$T_{e\,0} = \int_0^\infty T(y)\, \varkappa(y) \sec\rho' e^{-y\varkappa \sec\rho'}\, dy, \tag{2}$$

where T (y) and $\varkappa$(y) are the treu temperature and the absorption coefficient of planet matter at the depth y, ρ' is the angle between the directions of the emission from within, and the normal to outlet surface. The atmosphere absorbs, and consequently, it weakens the surface emission; besides, it provides its natural radiation. The atmosphere layer, of thickness ds along the visual ray, situated above the considered surface element **, contributes $\varkappa(\lambda, s)\, ds$. to absorption. The total optical thickness of the atmosphere is

$$\tau(\lambda) = \int_0^\infty \varkappa(\lambda, s)\, ds.$$

* Barret [13] considered a similar problem only for the particular case of molecular absorption in H_2O and CO_2 at exponential distribution of the absorbing matter. -

** see next page.

That is why the brightness temperature of the aggregate emission of the surface element and of the atmosphere lying above it along the visual ray, will be

$$T_{s}[\tau(\lambda)] = T_{e\,0}(1-R)\,e^{-\tau(\lambda)} + \int_{0}^{\infty} T_{a}(s)\,\varkappa(s,\lambda)\,e^{-\int_{s}^{\infty}\varkappa(s,\lambda)\,ds}\,ds.$$

The parameters R, $\tau(\lambda)$, $T_a(s)$ and $\varkappa(\lambda, s)$, entering in this formula, depend in the general case on the position of the surface element relative to observer. The experimentally observed phase course of brightness temperature [4 – 7] points to the fact, that at least some of the parameters brought up depend also on the degree of illuminance by the Sun, and consequently on the position of the emitting element relative to the Sun. Moreover, $T_a(s)$ and $\varkappa(s)$ are functions of height.

We shall assume in the first approximation, that the phase course of brightness temperature, averaged along the visible disk of Venus, is conditioned only by the difference of the effective temperatures of the surfaces $T_{e0\text{л}}$ and $T_{e0\text{н}}$ and by the atmosphere parameters $\tau_{\text{л}}$, $\tau_{\text{н}}$, $T_{a\,\text{л}}(s)$, $T_{a\,\text{н}}(s)$, $\varkappa_{\text{л}}(s)$ and $\varkappa_{\text{н}}(s)$ of the illuminated and dark parts of the planet and by the variation on the visible disk of the correlation between these two parts. But within the bounds of each of these parts, we shall consider all the indicated parameters as constant. Then, in the lower and upper conjunctions, when the lit and the unlit sides of the planet are respectively turned at the Earth, we may estimate that T_{e0}, $\tau(s)$, $T_a(s)$ and $\varkappa(s)$ are independent from the position of the element on planet's surface relative to the Sun.

3. – For the consideration of the dependence of the indicated quantities on the position of the emitting element relative to observer, it is paactical to utilize in this case the polar system of coordinates a, γ, where <u>a</u> is the distance of the element from the center of the disk, expressed in fractions of disk's radius, γ is the angle at the center of the disk between the direction of beginning of count and the direction at the emitting element, We shall take for the origin of the count the direction, coinciding with the polarization of the receiving system.

** [from the preceding page]. – We neglect the refraction in the atmosphere of Venus, essential only at the limb of the disk and thus contributing only insignificant variations.

The dependence of the reflection factor on the coordinates of the emitting element is described by the correlation

$$[1-R(a,\gamma)]=(1-R_{в})\cos^2\gamma+(1-R_{г})\sin^2\gamma,$$

where $R_{в}$ and $R_{г}$ are the reflection factors for the vertical and horizontal polarizations. For a smooth (relative to wavelength) surface, the reflection factors are determined by the well known Fresnel formulas :

$$R_{в}=\left(\frac{\varepsilon\cos\rho-\sqrt{\varepsilon-\sin^2\rho}}{\varepsilon\cos\rho+\sqrt{\varepsilon-\sin^2\rho}}\right)^2; \qquad R_{г}=\left(\frac{\cos\rho-\sqrt{\varepsilon-\sin^2\rho}}{\cos\rho+\sqrt{\varepsilon-\sin^2\rho}}\right)^2.$$

Taking into account that $a=\sin\rho$, and effecting the elementary transformations, we shall obtain

$$1-R_{в}=\frac{4\varepsilon\sqrt{(1-a^2)(\varepsilon-a^2)}}{(\varepsilon\sqrt{1-a^2}+\sqrt{\varepsilon-a^2})^2};\ 1-R_{г}=\frac{4\sqrt{(1-a^2)(\varepsilon-a^2)}}{(\sqrt{1-a^2}+\sqrt{\varepsilon-a^2})^2}. \qquad (4)$$

Account being taken of the above-described, the brightness temperature of a surface element with coordinates a, γ and $ds=dh/\sqrt{1-a^2}$, may be expressed in the form

$$T_я(a,\gamma,\lambda)=T_{co}\left[\frac{4\varepsilon\sqrt{(1-a^2)(\varepsilon-a^2)}}{(\varepsilon\sqrt{1-a^2}+\sqrt{\varepsilon-a^2})^2}\cos^2\gamma+\right.$$
$$\left.+\frac{4\sqrt{(1-a^2)(\varepsilon-a^2)}}{(\sqrt{1-a^2}+\sqrt{\varepsilon-a^2})^2}\sin^2\gamma\right]e^{-\frac{\tau(\lambda)}{\sqrt{1-a^2}}}+ \qquad (5)$$
$$+\frac{1}{\sqrt{1-a^2}}\int_0^\infty T_a(h)\,\varkappa(h,\lambda)\,e^{-\frac{1}{\sqrt{1-a^2}}\int_h^\infty \varkappa(h,\lambda)\,dh}\,dh.$$

As already noted, during reception on an antenna with a broad radiation pattern, as compared with the planet, the value measured is the brightness temperature, averaged by the visible disk of the planet :

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$$\overline{T_s(\lambda)} = \frac{\int\limits_{\Omega_\pi} T_s(\lambda, a, \gamma)\, d\Omega}{\Omega_\pi}, \tag{6}$$

where Ω_π is the solid angle of the planet. In the chosen system of coordinates, the element of the solid angle is

$$d\Omega = \frac{\Omega_\pi}{\pi}\, a\,da\,d\gamma. \tag{7}$$

Substituting (5), (7) into (6), and conducting a series of transformations, we shall obtain

$$\overline{T_s(\lambda)} = \overline{T_1(\lambda)} + \overline{T_2(\lambda)}\,. \tag{8}$$

Here $\overline{T_1(\lambda)}$ and $\overline{T_2(\lambda)}$ are the components of brightness temperature, averaged by the visible disk and conditioned by the emission of planet's surface and atmosphere.

4.– The quantity $T_1(\lambda)$ depends on temperature and electrical properties of the surface and on the total absorption in the atmosphere :

$$T_1(\lambda) = T_{e0} J_1[\tau(\lambda), \varepsilon], \tag{9}$$

where

$$J_1[\tau(\lambda), \varepsilon] = 4\int\limits_0^1 a\left[\frac{\varepsilon\sqrt{(1-a^2)(\varepsilon-a^2)}}{(\varepsilon\sqrt{1-a^2}+\sqrt{\varepsilon-a^2})^2} + \right.$$
$$\left. + \frac{\sqrt{(1-a^2)(\varepsilon-a^2)}}{(\sqrt{1-a^2}+\sqrt{\varepsilon-a^2})^2}\right] e^{-\tau(\lambda)/\sqrt{1-a^2}}\, da.$$

The quantity $J_1[\tau(\lambda), \varepsilon]$ is factually the emitting capability of planet, averaged along the disk. Its numerical values for different parameters τ and ε, obtained by computer, are compiled in Table 1.

A graph of the dependence $J_1(\varepsilon)$ for the case $\tau = 0$, that is for waves, on which there can be no absorption in the atmosphere, is plotted in Fig. 1, where we also brought out the dependence on ε of the emitting capability of the disk, normal to visual ray. The emitting capability of a smooth sphere is determined as

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$$1-\overline{R}=\int_0^1\int_0^{2\pi}[(1-R_s)\cos^2\gamma+(1-R_r)\sin^2\gamma]\,ada\,d\gamma=J_1(0,\varepsilon). \quad (10)$$

Then, the brightness temperature, averaged along the disk, is

$$T_s[\tau(\lambda)]=T_{e\,0}J_1(0,\varepsilon)\int_0^1 e^{-\tau(\lambda)/\sqrt{1-a^2}}\,da=T_{e\,0}J_2(\tau,\varepsilon), \quad (11)$$

where

$$J_2(\tau,\varepsilon)=J_1(0,\varepsilon)\int_0^1 e^{-\tau(\lambda)/\sqrt{1-a^2}}\,da. \quad (12)$$

The integral $\int_0^1 e^{-\tau/\sqrt{1-a^2}}\,da$ has been calculated by means of a computer, and the results are compiled in Table 2.

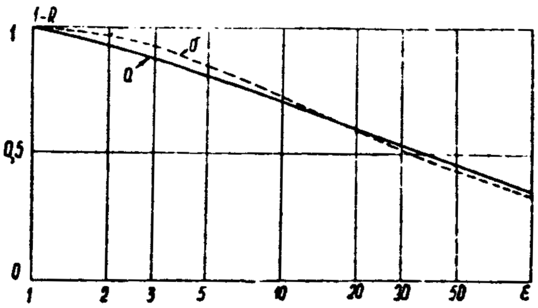

Fig.1. - Dependence of the emitting capability $1-\overline{R}$ of the planet with a transparent atmosphere on the dielectric constant of its surface's material :
a) averaged along the visible disk;
δ) for a normal incidence.

5. - The component of the brightness temperature $T_2(\lambda)$, conditioned by atmosphere radiation, depends on temperature and absorption in the atmosphere and on the distribution of these parameters in height :

$$\overline{T_2[\tau(\lambda)]}=2\int_0^1\frac{a}{\sqrt{1-a^2}}\int_0^\infty T_a(h)\,\varkappa(h,\lambda)\times$$

$$\times\exp\left[-\frac{1}{\sqrt{1-a^2}}\int_h^\infty\varkappa(h,\lambda)\,dh\right]dh\,da. \quad (13)$$

TABLE 1

Values of

$J_1(\tau, s) \cdot 10^3$

s \ τ	0	0,01	0,002	0,001	0,01	0,02	0,04	0,1	0,2	0,4	0,6	1,0	1,5	2	2,5	3,0	4,0	5,0	6,5
1,1	986	985	983	979	968	951	917	826	700	513	382	219	113	60	33	18	6	2	0
1,25	971	969	968	964	954	937	904	816	693	509	380	218	113	60	32	18	5	2	0
1,6	944	943	941	938	938	912	880	796	677	99	373	214	111	59	32	18	5	2	0
2,0	921	919	918	915	905	889	859	777	662	488	365	210	109	58	31	17	5	2	0
2,5	896	895	893	890	881	865	837	756	645	476	356	205	107	57	31	17	5	2	0
3,0	875	874	872	869	860	845	817	739	630	465	348	201	104	55	30	16	5	2	0
4,0	839	838	836	831	825	811	783	709	604	445	333	192	100	53	29	16	5	2	0
5,0	810	808	807	804	795	782	755	683	681	429	321	185	96	51	28	15	5	1	0
6,5	772	771	770	767	759	746	729	651	554	408	305	175	91	48	26	14	4	1	0
8,0	742	740	739	736	728	716	691	624	531	390	292	168	87	46	25	14	4	1	0
10	708	706	705	702	695	683	659	595	505	371	277	159	82	44	24	13	4	1	0
12,5	672	671	670	668	660	649	626	564	479	351	262	150	78	41	22	12	4	1	0
16	633	632	631	629	622	610	589	530	449	329	245	141	73	39	21	11	4	1	0
20	598	597	595	593	586	576	555	500	423	310	230	132	68	36	20	11	3	1	0
25	562	561	560	558	552	541	522	469	396	289	215	123	63	34	18	10	3	1	0
30	534	532	531	529	523	513	495	444	375	273	213	116	60	32	17	9	3	1	0
40	489	488	487	485	480	470	453	406	342	249	185	105	54	29	15	8	3	1	0
50	456	455	454	452	447	438	421	377	318	231	171	97	50	26	14	8	2	1	0
65	418	417	416	414	410	401	386	345	290	210	155	88	45	24	13	7	2	1	0
80	389	388	388	386	381	373	359	321	269	194	144	82	42	22	12	7	2	1	0
100	360	359	358	357	352	345	331	296	248	179	132	75	38	20	11	6	2	1	0

TABLE 2

τ	0	0,001	0,002	0,004	0,01	0,02	0,01	0,1	0,2	0,4	0,6	1,0	1,5	2	2,5	3	4	5	6,5
$10^3\int_0^1 e^{-\tau/\sqrt{1-a^2}}da$	1000	998	997	994	985	970	941	863	751	576	447	274	152	85	49	28	9	3	1
$D_1(\tau)\cdot 10^3$	1000	998	996	992	980	961	924	833	704	514	383	219	113	61	33	17	7	2	0
$D_2(\tau)\cdot 10^3$	0	1	1	3	7	20	39	92	168	288	377	494	575	616	639	650	663	664	666

TABLE 3

Values of

$J_3(\tau, b)\cdot 10^3$

b \ τ	0,001	0,002	0,004	0,01	0,02	0,04	0,1	0,2	0,4	0,6	1,0	1,5	2	2,5	3,0	4,0	5,0	6,5	10	15	20	30	50	100	300	1000
0,90	105	105	104	103	101	98	88	75	56	42	25	13	7	4	2	1	0	0	0	0	0	0	0	0	0	0
0,78	248	247	247	244	240	232	211	182	137	105	64	35	20	12	7	2	1	0	0	0	0	0	0	0	0	0
0,61	493	493	491	487	479	465	427	373	290	229	147	87	53	33	21	8	4	1	0	0	0	0	0	0	0	0
0,37	993	992	989	982	970	947	884	793	647	536	376	250	171	119	84	44	24	10	2	0	0	0	0	0	0	0
0,20	1608	1606	1603	1594	1578	1549	1467	1347	1151	995	751	562	427	330	259	165	109	62	19	4	1	0	0	0	0	0
0,08	2524	2522	2518	2508	2490	2456	2360	2219	1981	1787	1486	1214	1014	862	742	566	456	321	166	74	36	10	1	0	0	0
0,03	3505	3503	3499	3487	3469	3433	3331	3180	2924	2712	2377	2066	1830	1643	1491	1256	1082	889	606	386	253	134	43	4	0	0
0,0067	5004	5002	4998	4986	4967	4930	4826	4670	4405	4184	3832	3449	3243	3036	2865	2593	2383	2139	1750	1403	1170	867	541	222	18	0
0,00055	7498	7496	7492	7480	7661	7424	7319	7162	6895	6672	6314	5976	5713	5501	53[illegible]3	5040	4819	4558	4131	3731	3449	3054	2561	1922	1006	295
0,000015	10006	10005	10001	9990	9970	9932	9828	9670	9403	9180	8822	8483	8220	8007	7829	7545	7322	7060	5630	6225		5533	5024	4335	3254	2102

TABLE 4

$J_4(\tau)$

$\bar{T}_m$ (°K)	$\beta\Delta h_0$ \ τ	0,001	0,002	0,01	0,02	0,04	0,1	0,2	0,4	0,6	1	2	2,5	3	4	5	6,5
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
300	−10	0,6	1,2	5,8	11	22	50	89	145	185	233	280	288	292	296	296	296
	−40	0,60	1,2	5,8		22	50	88	144,5	183	230,6	275	—	285	287	288	—
	−160	0,59	1,2	5,8	11,4	22	50	87	141	177	220	254	257	257,6	—	—	—
400	−10	0,80	1,6	7,8	15,2	29	67	118	194	246	311	374	385	390	395	396	397
	−40	0,8	1,6	7,8	15,2	29	67	118	193	245	308	369	379	384	386	387	387
	−160	0,8	1,6	7,8	15,2	29	66	117	190	239	298	348	354	356	—	—	—
600	+150	1,2	2,4	11,6	22,8	44	101	179	295	377	482	590	611	623	637	643	648
	+500	1,2	2,4	11,7	22,9	44	102	183	305	394	513	651	683	705	731	747	762
1000	500	2,0	4,0	19,4	38	74	169	301	499	641	825	1027	1070	1098	1129	1146	1162
2000	500	4,0	7,9	38,8	76	147	336	597	985	1258	1606	1966	2038	2080	2124	2145	2162

For subsequent computations, we shall make certain assumptions relative to these parameters. The distribution of temperature in the atmosphere of Venus will be assumed linear piecewise broken, with temperature gradient β_1 from surface to upper cloud layer limit and with a gradient β_2 above the cloud layer :

$$T_a(h) = \begin{cases} T_n + \beta_1 h & \text{at } 0 \leqslant h \leqslant h_{o6\pi} \\ T_{o6\pi} + \beta_2 (h - h_{o6\pi}) & \text{at } h > h_{o6\pi} \end{cases} . \tag{14}$$

In the particular case when $\beta_2 = 0$, the region above the cloud layer is isothermic with temperature $T_a = T_{o\delta\pi}$. Depending upon the nature of the absorpbing layer, the following particular cases of absorption distribution in height offer interest :

a) the total atmosphere thickness is absorbing : the distribution of absorption is exponential;

b) absorbing is the layer, between h_1 and h_2: the absorption in the layer is constant

c) absorbing is the layer, included between h_1 and h_2: the distribution of absorption in the layer is parabolic.

We shall consider these three cases.

C A S E a). - The distribution of absorption is exponential :

$$\varkappa(\lambda, h) = \varkappa_0(\lambda)\, e^{-h/H}, \tag{15}$$

where $\varkappa_0(\lambda)$ is the absorption at level $h = 0$, H being the height of uniform atmosphere. For the Earth this case corresponds to molecular absorption in the atmosphere.

In connection with the small contribution of the above cloud part of the atmosphere, we shall assume for the simplification of calculations, that $\beta_2 = 0$, that is

$$T_a(h) = \begin{cases} T_n + \beta_1 h & \text{at } 0 \leqslant h \leqslant h_{o6\pi} \\ T_{o6\pi} & \text{at } h > h_{o6\pi} \end{cases} \tag{16}$$

Substituting (15) and (16) into (13) and conducting a series of transformations, we shall obtain

$$\overline{T_2[\tau(\lambda)]} = T_{o6\pi} - T_n D_1(\tau) + \beta_1 H J_3(\tau, b), \tag{17}$$

where

$$D_1(\tau) = e^{-\tau}(1-\tau) - \tau^2 \mathrm{Ei}(-\tau),$$

Ei is the integral exponential function,

$$J_3(\tau, b) = 2\int_0^1 a \int_1^b e^{-\tau z/\sqrt{1-a^2}}\, dz\, da,$$

$$b = e^{-h_{об\lambda}/H}$$

The functions $D_1(\tau)$ and $J_3(\tau, b)$ are compiled in Tables 2 and 3. The computation of $J_3(\tau, b)$ was also effected by means of computer.

The resulting brightness temperature, averaged along the visible disk of the planet, for a smooth surface, is in this case

$$T_a[\tau(\lambda)] = T_{e0}J_1(\tau, \varepsilon) - T_n D_1(\tau) + T_{об\lambda} + \beta_1 H J_3(\tau, b). \qquad (18)$$

<u>CASE б)</u>.- The absorbing layer is included in a layer of finite thickness, The distribution of absorption along the layer is uniform:

$$\varkappa(h, \lambda) = \begin{cases} \varkappa_0(\lambda) & \text{at} \quad h_1 \leqslant h \leqslant h_2 \\ 0 & \text{at} \quad h < h_1, \quad h > h_2 \end{cases}$$

Considering, moreover,

$$h_{об\lambda} > h_2 \qquad \text{or} \qquad h_{об\lambda} < h_1,$$

we shall obtain

$$\overline{T_2[\tau(\lambda)]} = T_2 - T_1 D_1(\tau) + \frac{T_1 - T_2}{\tau} D_2(\tau), \qquad (19)$$

where T_1 and T_2 are the temperatures of the atmosphere a lower and upper boundary of the layer,

$$D_2(\tau) = \frac{1}{2}\left[2 - e^{-\tau}(2 - \tau + \tau^2) - \tau^3 \mathrm{Ei}(-\tau)\right].$$

The function $D_2(\tau)$ is compiled in Table 2.

<u>CASE c)</u>. - The absorbing layer is included in a layer of finite thickness. The distribution of absorption is parabolic :

$$\varkappa(h,\lambda)=\varkappa_0(\lambda)\left[1-\left(2\frac{h-h_m}{\Delta h_0}\right)^2\right]\quad\left(h_m-\frac{\Delta h_0}{2}\leqslant h\leqslant h_m+\frac{\Delta h_0}{2}\right),\qquad(20)$$

where h_m is the height of absorption maximum; $\varkappa_0(\lambda)$ is the absorption at the height h_m, Δh_0 is the thickness of the layer along the zero absorption level. Under terrestrial conditions this case would correspond to absorption in the cloud layer or in the ionosphere. Denoting $2(h-h_m)/\Delta h_0=y$, and conducting a series of transformations, we shall have

$$T_2[\tau(\lambda)]=J_4(\tau,\ T_m,\ \beta,\ \Delta h_0),\qquad(21)$$

where

$$J_4(\tau,\ T_m,\ \beta,\ \Delta h_0)=\frac{3}{2}\tau\int_0^1\frac{a}{\sqrt{1-a^2}}F(a)\,da,$$

$$F(a)=\int_{-1}^{1}\left(T_m+\beta\frac{\Delta h_0}{2}y\right)(1-y^2)\exp\left\{-\frac{\tau}{2\sqrt{1-a^2}}\times\left[1-\frac{3}{2}y\left(1-\frac{y^2}{3}\right)\right]\right\}dy,$$

$$\tau(\lambda)=\int_0^\infty\varkappa(\lambda,\ h)\,dh=\frac{2}{3}\varkappa_0(\lambda)\,\Delta h_0\ .$$

T_m is the temperature of the layer at absorption maximum level. The function $J_4(\tau)$ is also computed with the help of a computer and is compiled in Table 4.

6. - We shall apply now the correlation obtained to the results of radioastronomical observations of Venus. As is well known, there are two groups of models, explaining the observed Venus' radio emission spectrum. In one of the groups of models (with "cold" atmosphere) it is admitted, that the atmosphere of the planet is absorbing for waves shorter than 2cm and transparent for greater wavelengths. In this case the emission in wavelengths $>$ 2 cm is conditioned by planet surface. A lower brightness temperature in the microwave band is conditioned by absorption in a colder atmosphere of the planet. In the other group of models it is admitted, that Venus has a "hot" ionosphere, absorbing at waves $>$ 2 cm and transparent at shorter wavelengths.

Let us examine the model with a "cold" atmosphere, and determine, what the absorption dependence on the wavelength, required for satsifying the observed spectrum of brightness temperature, must be.

This examination will be conducted for the dark side of Venus, of which the radio emission spectrum has been studied sufficiently well (see, for example, [9]).

In order to estimate the dielectric constant, we shall refer to the data of radio emission measurements of Venus. Judging from those concerning the "cold" armosphere model [10 – 12], $\varepsilon = 2.5 \div 6$.

The surface temperature of this model will be determined from [9] acclrding to the brightness temperature measured in the wave band where the atmosphere is transparent $(\tau = 0)$:

$$T_{e0} = \frac{T_{яв}}{J_1(0, \varepsilon)} .$$

The brightness temperature of the dark side of Venus in the $\lambda = 3 \div 20$ cm wavelength range constitutes $\sim 585°$ K. Then

$$T_{e0} = \frac{585}{J_1(0,\ 3)} = \frac{585}{0{,}87} = 670°\mathrm{K}.$$

At values $\varepsilon = 2.5 \div 6$, $J_1(0, \varepsilon) = 0.89 \div 0.78$, which corresponds to $T_{e0} = 660 \div 750°$ K. The temperature of the cloud layer shall be taken, according to measurements data, $T_{обл} \simeq 250°$ K. The temperature gradient in planet's troposphere (that is in the below cloud layer) will be taken equal to the adiabatic gradient :

$$\gamma_a = Ag / C_p,$$

where $A = 2.39 \cdot 10^{-8}$ cal.erg^{-1} is the thermal equivalent of the operation, g is the gravitation acceleration, equal to 835 cm.sec^{-2} on Venus, C_p is the heat capacity at constant pressure. However, the chemical composition of the atmosphere, and consequently, the quantity C_p also, are unknown for Venus. Spectroscopic investigations have shown that,the main part of planet's atmosphere is constituted of gases, which are not detectable spectroscopically. Such components could be nitrogen, and also the inert gases. For nitrogen $C_p = 0.25$ cal·g^{-1}·deg^{-1} and $\gamma_a = 8$ deg.km^{-1}. For argon $C_p = 0.125$ and $\gamma_a = 16$ deg km^{-1}. For further calculations we shall assume a nitrogen atmosphere and $\beta_1 = \gamma_{aN_2} = 8$ deg·km^{-1}. Then

../..

$$h_{обл} = \frac{T_n - T_{обл}}{\beta_1} = 52,5\ км.$$

Plotted in Fig. 2 are the graphs for the dependences $\overline{T_{B}[\tau(\lambda)]}$, computed for the considered particular cases and for the above-selected parameters of a Venus model with a "cold atmosphere" $\varepsilon = 3$, $T_{e\,0} = 670°$ K, $T_{обл.} = 250°$ K, $\beta_1 = 8$ deg·km^{-1}, $h_{обл} = 52.5$ km for the various variants of abso p ion . istribution in height. Solid curves refer to the case of absorption by the whole thickness of the atmosphere with an exponential distribution in height. The chosen heights of uniform atmosphere, —— H = 7, 10.5, 15 and 21 km, correspond to nitrogen atmosphere with temperatures of 200, 300, 420 and 600° K. The dashed curve corresponds to the

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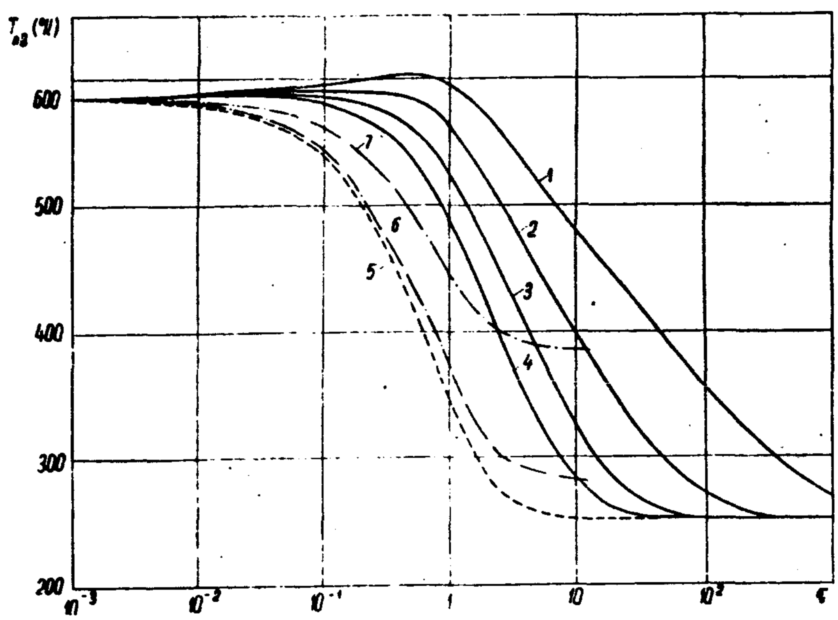

Fig. 2. - Dependence of Venus' brightness temperature T_B on the optical thickness of the absorbing atmosphere for $\varepsilon = 3$, $T_{e0} = 670°$ K, $T_{обл} = 250°$ K, $\beta_1 = 8$ deg km^{-1}, $h_{обл} = 52$ km:

1) absorption by the whole atmosphere thickness (H = 7 km);
2) " " " " " " (H = 10.5 km);
3) " " " " " " (H = 15 km);
4) " " " " " " (H = 21 km);
5) " " " uniform layer included between levels with temperatures $T_1 = 300°$ K, $T_2 = 250°$ K;
6) absorption by the parabolic layer with $T_m = 300°$ K, $\beta\Delta h_0 = -40°$ K;
7) absorption by the parabolic layer with $T_m = 400°$ K, $\beta\Delta h_0 = -40°$ K.

to the layer with identical absorption in height, included between the heights at which the temperatures are equal to $T_1 = 300^\circ K$ and $T_2 = 250^\circ K$. The dash-dotted curves show the dependences $\overline{T_{яB}[\tau(\lambda)]}$ for the parabolic layer with $\Delta h_o = 5\,km$ for $T_m = 300$ and $400^\circ K$.

The consideration of the depedences brought out shows, that if absorption takes place in the whole thickness of the atmosphere, high values of the optical thickness of the latter will be required in these wavelengths to satisfy the brightness temperatures of Venus measured in the microwave band, which are $\overline{T_{яB}} \simeq 350 \div 400^\circ K$. Thus, for example, at $H = 7\,km$, obtained by observations of "Regula" covering*, unrealistically high values of optical thickness would be requires : $\tau_{\lambda = 4 \div 8\,mm} \simeq 100$. That is why, it appears to be improbable, that in such an atmosphere the value of H should be substantially greater than 7 km.

From the same Fig. 2 it may be seen, that brightness temperatures $\sim 350 \div 400^\circ K$ can be obtained at substantially lesser optical thickness, profided absorption takes place in a layer of finite thickness, disposed near the upper boundary of the cloud layer. Indeed, a layer with $T_m = 300^\circ K$ and $\Delta h_o = 5$ km must have $\tau_{\lambda = 4 \div 8\,mm} \sim 1$.

On the basis of the above-expounded, it seems to be more probable that the absorbing matter, responsible for the decrease of brighnness temperature of Venus in the microwave band, should be included in a layer of finite thickness, situated hear the upper boundary of the cloud layer, and not distributed about the whole planet's atmosphere.

Plotted in Fig. 3 [next page] is the dependence of optical thickness τ for the parabolic layer with $T_m = 300^\circ K$ and $\Delta h_o = 5\,km$ and, by way of consequence, also of the absorption $\varkappa$ in the layer, on the wavelength, which is necessary for satisfying the spectrum of $T_{яB}(\lambda)$ observed [9].

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**** THE END ****

Institute of Physics in the name of
P. N. Lebedev
of the USSR Academy of Sciences.

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* in transliteration

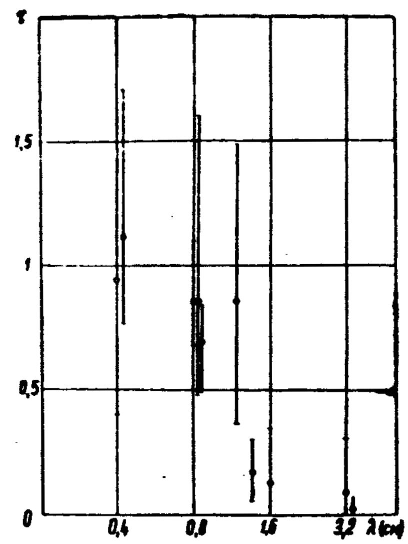

Fig. 3.- Dependence of the optical thickness of the atmosphere with parabolic absorbing layer ($T_m = 300°K$, $\beta\Delta h_0 = -40°K$), satisfying the experimental data of [9], on the frequency spectrum of radio emission

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